Original Article

A new elastic slot system and V-wire mechanics

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ABSTRACT

Objective: To biomechanically test a new elastic slot system and V-wire mechanics.

Materials and Methods: Conventional twin and self-ligating brackets and the new elastodynamic bracket were biomechanically tested. The conventional brackets had a rectangular 0.022″ slot and the new elastodynamic bracket had a V-slot, a new slot geometry. Torque measurements were performed with 0.018″ × 0.025″ and 0.019″ × 0.025″ stainless steel (ss) archwires. A nickel-titanium V wire was used for the biomechanical measurements on the elastodynamic bracket. The measurements were done with the aid of a six-component measuring sensor.

Results: The results of the biomechanical testing revealed play in the brackets with rectangular slot geometry. The V slot in the elastodynamic bracket assured that the wire fit perfectly in the slot. Dynamic moments of 5 to 10 Nmm were transmitted without any play. No permanent deformation of the slot occurred in the new elastodynamic bracket because of the elastic slot.

Conclusion: Control of torque for three-dimensional positioning of the teeth in the dental arch with rectangular slot geometry as used in straight-wire therapy is difficult. If torque is bent into the wire, because of the play there is a high risk that either too much, too little, or no moment is transmitted to the teeth. The V-slot archwire/bracket geometry in conjunction with nickel titanium composition has no play and allows a reduction of forces and moments with direct and continuous transmission of torque in the bracket. Because of the elasticity of the bracket, there is an upper limit to the moment possible. (*Angle Orthod.* 2017;87:774–781.)

KEY WORDS: V-wire mechanics; Elastic slot system; Biomechanics; Moments; Forces

INTRODUCTION

The correct axial position of the teeth is a prerequisite for function and esthetics.[1–3] According to Andrews,[4,5] torque of the maxillary and mandibular anteriors is the angle formed by the facial axis of the clinical crown and perpendicular to the occlusal plane. Torque, as classically described by Andrews[5] in the straight-wire technique, thus denotes the passive state of the position of the anterior teeth dependent on the skeletal anomaly. Andrews himself recommends bending torque into 0.018″ × 0.025″ steel wires for a 0.022″ slot to achieve active movement.[5]

Various straight-wire techniques, such as Ricketts[6], Roth[7], and Burstone,[8] and the sliding mechanics according to Bennett and McLaughlin,[9] attempted to integrate the dynamics of movement paths into the original straight-wire system by means of segmented archwire mechanics and/or the use of different variations in torque, angulation, and offset in the bracket system. Clinical trials show that differing torque prescriptions may not cause a change in the axial position of the teeth.[10]

The materials so far available for orthodontic treatment may not enable the orthodontist to implement dynamic movement paths in the straight-wire system. This is partly because the brackets are made of stainless steel and partly because of the shape of the actual slot. Although stainless steel has been used as a bracket material because of its high biological stability, passivated nickel titanium (NiTi) has been shown to be equally resistant or better.[11] The steel alloy used for conventional brackets, with a high modulus of elasticity, is relatively dimensionally stable, but it enters a plastic range under severe strain, which can result in deformation of the slot if the design of the brackets varies and on torsional stress.[12] Therefore, precise

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torque transmission is not guaranteed with conventional steel materials.

The rectangular slot shape does not permit play-free fit of the archwire.[13–16] The slot dimension always tends to be slightly larger and that of the wire, slightly smaller. The play between the slot and the archwire is of advantage during alignment. This is true for rectangular slots and V slots with the application of thin wires. During retraction and adjustment phases, a better fit to transfer moments may be desirable. As a result of fabrication-related tolerances, which are stipulated in International Organization for Standardization (ISO) standards 15841:2014 (orthodontic wires) and 27020:2010 (orthodontic brackets), the play in the slot is not predictable and varies among bracket systems.[16,17] Self-ligating (SL) bracket systems with so-called active clips are not capable of applying active torque or dynamic torque.[16] Dynamic torque and thus orovestibular root movement are difficult to achieve with the different straight-wire techniques, irrespective of the prescription of the bracket.[10]

Dynamic movement paths and more precise biomechanics can be realized with pseudo elastic materials, new bracket design features, and new slot geometry. In addition to design features such as shape of the bracket, materials with a low modulus of elasticity and so-called superelastic material behavior are particularly suitable.[18] The superelasticity in NiTi alloys enables flexible bracket structures to be fashioned that can only transmit smaller absolute moments because of their low elastic modulus but, because of nonplastic effects, these remain constant over a long period of time.

A major weakness of conventional bracket systems is control of torque and resultant force levels on the teeth. Therefore, the aim of the study was to develop and to evaluate V-slot archwire/slot geometry in conjunction with NiTi material composition of the bracket to reduce peak force and moment levels and to transmit predictable moments on the teeth. For biomechanical verification of this new slot geometry, the elastic bracket and slot system torque transmission was compared with that of conventional twin and SL brackets.

MATERIALS AND METHODS

The elastodynamic bracket was constructed of NiTi alloy. Clinically, the presence of the strain plateau places a limit on the forces and moments because there is no increase in force despite higher strain. This essential difference from a conventional, stainless steel bracket prevents the increase in tolerance caused by plastic deformation in response to higher moments. Although the bracket deforms, it gradually transmits the whole moment to the tooth because it can spring back elastically once tooth movement starts.

As a result of its superelastic material behavior, the NiTi bracket can be fitted with so-called solid-body hinges that enable the archwire to be clicked into place by the application of slight pressure. These elastic hinges also serve as limiters for the transmitted moment, making it unnecessary to use clips or other movable parts to close the bracket slot. Another advantage of the elastic bracket wings is the fact that no notching (abrasion as a result of the tilting of the archwire in the slot) can arise when moments occur.

The specific fashioning of the slot into a V-shape, in combination with a V-shaped wire, allows completely play-free guidance of the archwire into the slot, similar to the functional principle of a dovetail guide (Figure 1).

Conventional brackets, stainless steel twin brackets (Mini Sprint, Forestadent, Pforzheim, Germany), stainless steel self-ligating brackets (BioQuick, Forestadent, Pforzheim, Germany), ceramic self-ligating (SL) brackets (In-Ovation C, DENTSPLY Int., York, Pa), and the new NiTi elastodynamic bracket (RED, redsystem, Munich, Germany) were tested biomechanically with regard to torque, torque transmission, and torque development. The tested brackets, twin brackets, and conventional self-ligating brackets had a rectangular 0.022″ slot, whereas the slot on the RED bracket was V shaped. In this study, the torque measurements were performed with $0.018'' \times 0.025''$ and $0.019'' \times 0.025''$ steel archwires (Forestadent, Pforzheim, Germany), as they are generally used clinically in the straight-wire technique and sliding mechanics according to McLaughlin et al.[19] A V wire made of NiTi (redsystem) was used for the biomechanical measurements of the elastodynamic bracket.

Forces as well as moments in all three dimensions were recorded using a six-component sensor (Nano17 SI-50-0.5, ATI Industrial Automation, Apex, N.C.; Figure 2). Each bracket/wire combination was measured with four separate samples. The maximum angle of torque resulted from the matching bracket and wire combination. If angles of torque were too large, permanent slot deformation would occur in the steel brackets and the ceramic brackets used would fracture.

All of the tested brackets were photographed before and after the torque experiments using a digital Universal Serial Bus (USB) light microscope (2-million pixel resolution, Conrad Electronic SE, Hirschau, Germany) and deformation of the slot was evaluated using ImageJ software.[20]

IBM SPSS Statistics 23 (IBM Corp., Armonk, N.Y.) was used for the statistical analysis. After testing for a normal distribution by the Shapiro–Wilks test, the

Figure 1. Elastodynamic bracket design. Design of the bracket differs from conventional brackets in its slot geometry of a V slot and V wire. This achieves an accurate fit of the wire in the slot. As a result of the V slot, slot-filling archwires can be used for the first time. The monolithic design of the nickel titanium (NiTi) bracket allows for flexible bracket structures and the transmission of small, well-defined moments.

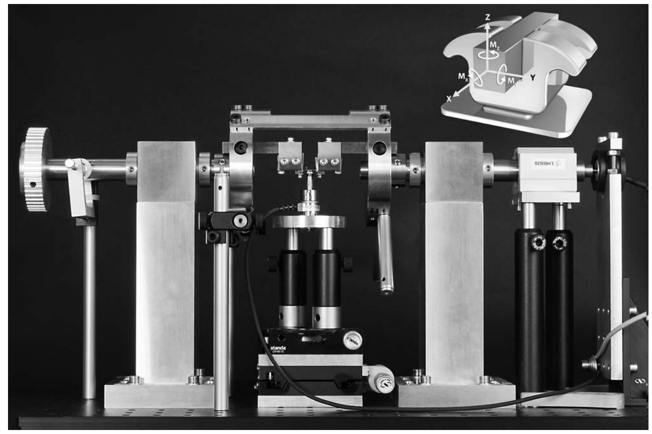

Figure 2. Measuring device and coordinate system. The measured data are recorded via the six-axis sensor in all spatial directions and plotted.

statistical analysis was performed using the Kruskal–Wallis test and Wilcoxon matched-pairs signed-rank test. The level of significance was set at $P \leq .05$.

RESULTS

The results of the biomechanical testing showed appropriate play in the brackets with rectangular slot geometry, regardless of the ligature: steel ligature or self-ligating (Figures 3 and 4, Table 1). Depending on the bracket type, bracket play was between 17° and 20° for the 0.018″ × 0.025″ wire dimension and between 13° and 17° for the 0.019″ × 0.025″ wire dimension. The largest amount of play was found in the passive SL bracket followed by the classic twin bracket and active SL bracket ($P = .0286$). The elastodynamic bracket exhibited no play because of its V-shaped slot and wire (Figures 3 and 4).

In the twin bracket, there was no significant difference between palatal and buccal torque (Figure 5). The mean moment in the case of 30° torque angulation and 0.018″ × 0.025″ stainless steel (ss) was 39 Nmm. When the twin bracket was combined with a 0.019″ × 0.025″ steel wire, the moment was 27 Nmm at 20° torque angulation and increased more markedly in comparison with the 0.018″ × 0.025″ ss wire and was 60 Nmm at 30° torque angulation (Figures 3 and 4).

The passive self-ligating bracket showed no significant difference between palatal and buccal torque (Figure 6). At 30° torque angulation, the mean moment was 27 Nmm for a 0.018″ × 0.025″ ss and 37 Nmm for a 0.019″ × 0.025″ ss archwire (Figures 3 and 4). In the case of this bracket, there was no marked difference between the two wire dimensions in terms of either play or moment.

The mean moment of the active self-ligating bracket was 52.6 Nmm when using a 0.018″ × 0.025″ ss archwire (Figure 3). Torque angulation of 20° with a 0.018″ × 0.025″ ss generated a mean moment of 18.5 Nmm. The 0.019″ × 0.025″ ss in combination with the In-Ovation bracket generated moments of more than 60 Nmm (Figure 4). For 20° torque angulation and 0.019″ × 0.025″ ss, the mean moment was 31.9 Nmm. There were significant differences between palatal and buccal torque angulation only for 0.018″ × 0.025″ ss at torque angulations of 15° and 30° ($P = .029$; Figure 6). The effect was caused by the bracket design and material.

Repeated application and torque of a 0.019″ × 0.025″ ss archwire led to plastic slot deformation in one steel slot and a corresponding decrease in moment (Figure 5). Combining torque of the 0.019″ × 0.025″ archwire with a ceramic slot also did not permit the slot to be stressed at will. However, this did not result in deformation; fracture occurred because of the brittleness of the material.

The results for the elastic bracket system RED with V slot made of NiTi showed moments between 5 and 20 Nmm for a torque angulation of 5° to 15° because of its specific material behavior (Figures 3 through 5). The elastic slot and the V-shaped wire made of NiTi resulted in maximum moments markedly lower than for conventional orthodontic bracket-archwire combinations. Above a torque angulation of 15°, the V wire twisted out of the slot and bracket. This is a safety mechanism that sets a force and moment upper limit for the elastodynamic system. As a result of the elastic slot, there was no permanent slot deformation and the moments were independent of the direction of twist (palatal or buccal). As the V slot promotes optimal fit of

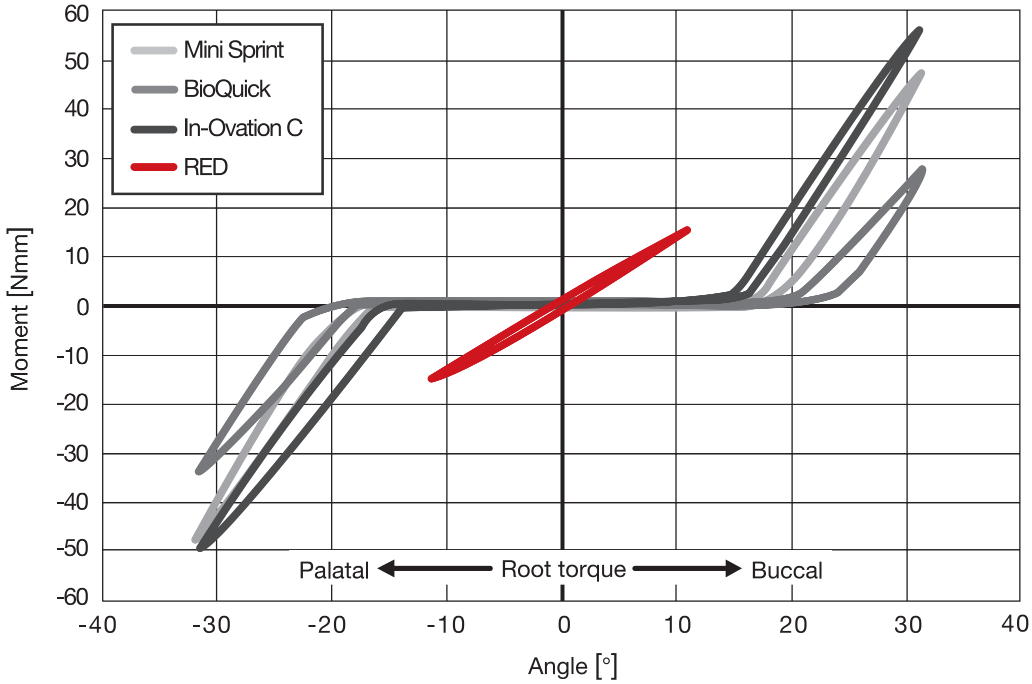

Figure 3. Typical graphs of the torque measurements with 0.018″ × 0.025″ ss and conventional twin bracket, passive and active SL bracket in comparison with the elastodynamic bracket with V slot and V wire.

the wire in the slot, dynamic moments can be transmitted without any play.

A mean torque angle of 7° was introduced to generate a moment of 10 Nmm, and 11° to 12° for a moment of 15 Nmm (Table 2).

DISCUSSION

As shown in previous studies, the play in conventional bracket systems varied in this study depending on the particular bracket and the wire dimension being

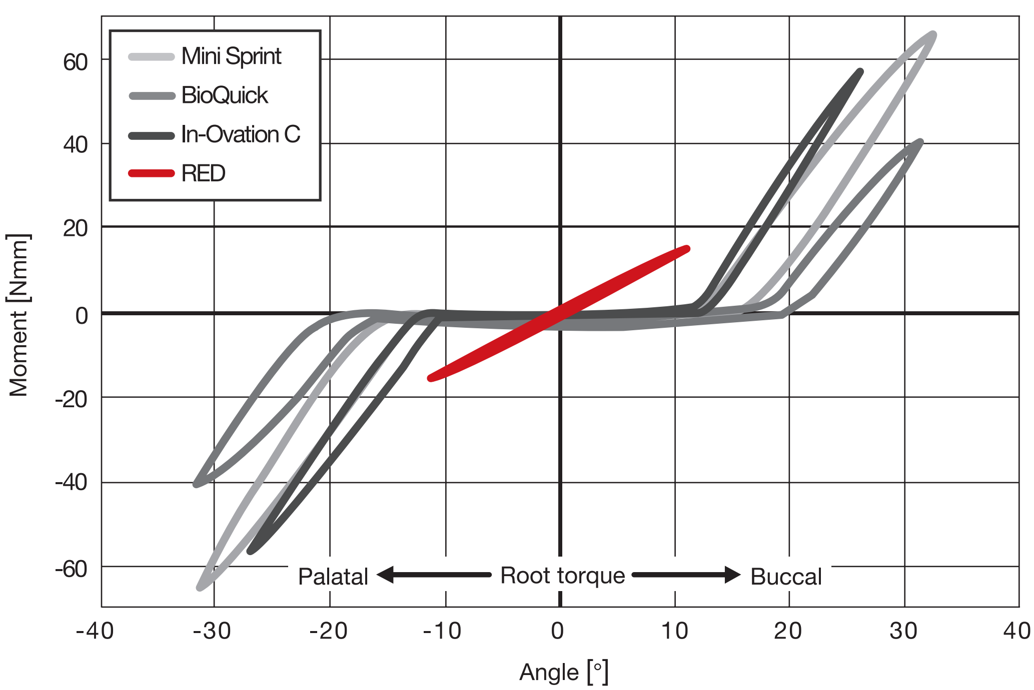

Figure 4. Typical graphs of the torque measurements with 0.019″ × 0.025″ ss, conventional twin bracket (Mini Sprint, Forestadent, Pforzheim, Germany), and passive (BioQuick, Forestadent, Pforzheim, Germany) and active self-ligating brackets (In-Ovation C, DENTSPLY Int., York, Pa) in comparison with the elastodynamic bracket with V slot and V wire.

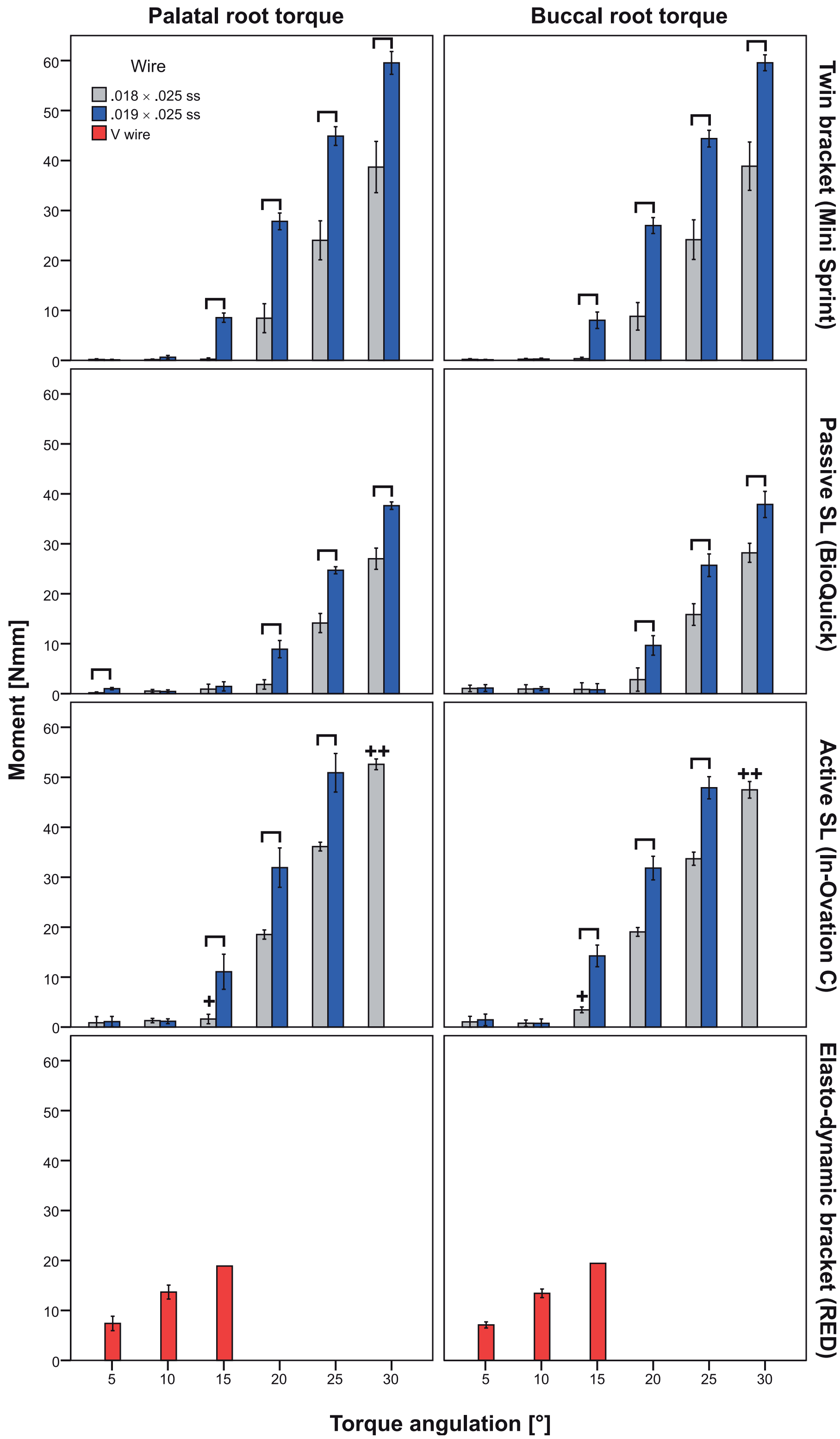

Figure 5. Comparison of the moments for palatal and buccal root torque in a conventional twin bracket, passive and active self-ligating (SL) brackets, and 0.018″ × 0.025″ and 0.019″ × 0.025″ ss archwires vs the elastodynamic bracket with V slot and V wire.

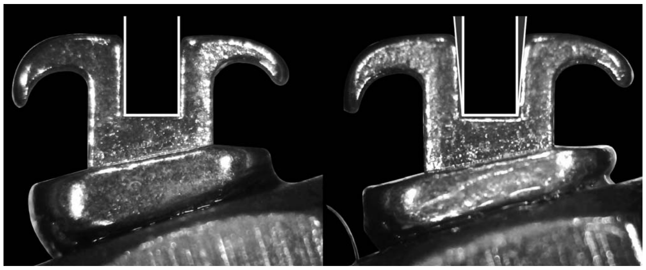

Figure 6. Slot deformation after application of torque. There are changes to the slot in the conventional twin brackets and SL brackets, particularly after using the 0.019″ × 0.025″ ss archwire. In contrast, the elastodynamic bracket does not alter its slot shape.

tested.[15–17] Torque for precise three-dimensional positioning of the teeth in the dental arch, depending on the patient's skeletal conditions, is difficult to achieve in straight-wire therapy. The torque angulation in the bracket may be insufficient to transmit suitable moments. Both Andrews[5] and McLaughlin et al.[19] recommended bending torque into the archwire because of play using 0.018″ × 0.025″ and 0.019″ × 0.025″ ss archwires.

A play-free fit was achieved in this study using V-slot and V-wire geometry, thus making transmission of torque in the bracket possible. In V-slot mechanics, the torque angulation (or prescription) of the elastodynamic bracket was transmitted directly to the tooth as moment.

As previously described in the literature, deformation of the slot was also observed in this study using conventional brackets with a metal slot.[12] This contrasted with the behavior of the elastodynamic bracket, which prevented any deformation.

When torque is described in orthodontics, people mistakenly think of the angulation of the bracket in relation to the tooth surface, as described by Andrews.[5] In material sciences, torque is the moment and not the angulation. This gives rise to the false impression that the appropriate moment is applied to the tooth by the prescription in the bracket. Therefore, the straight-wire technique is a passive and not an active system. This means that, because there are a large number of variables, a change in the rectangular slot prescription will not necessarily lead to the transmission of definable moments, thus making prediction of axial tooth movement unreliable.[10]

A moment of 5 to 20 Nmm is recommended for correct positioning of the anterior teeth.[8,21,22] The moments measured in this study with conventional bracket systems and matching steel archwires were much higher than that in terms of their maximum values. Different torque angulations, depending on the bracket, would need to be introduced into the archwires in order to achieve the desired moments. To apply 5 to 20 Nmm, for instance, the torque angulation was between 15.5° and 20.5° in the case of the In-Ovation C bracket and a 0.018″ × 0.025″ ss wire (Table 1). Clinically, moments of 40 Nmm are transmitted when torque angulation is only 27°. It is therefore difficult to transmit predictable moments during clinical treatment because of play in the slot. The results of this study confirmed that applying predictable moments to achieve desired movement paths, such as those occurring, for instance, when correcting the position of the anterior teeth, are difficult using conventional bracket-archwire systems.[16] In addition, with conventional straight-wire brackets and wires, there is no clinically and biomechanically meaningful defined force and moment upper limit. Therefore, there is a high risk of overloading the teeth.

The moments were markedly lower (5 Nmm to 15 Nmm) with the V-wire and elastodynamic bracket. A moment of 10 Nmm was achieved with a torque angulation of 7°. Further clinical trials are needed to

Table 1. Mean Torque Angle Required and Standard Deviation to Achieve Moments of 5 Nmm, 10 Nmm, 15 Nmm, and 20 Nmm in the Cases of 0.018″ × 0.025″ ss and 0.019″ ×0.025″ ss Wire[a]

			Angulation in Degrees (SD)[b] at Moment of				
Wire Dimension	Label	Bracket	5 Nmm	10 Nmm	15 Nmm	20 Nmm	Play in Degrees
0.018″ × 0.025″ ss	A	Mini Sprint	18.89 (0.80)	20.48 (0.90)	22.11 (1.04)	23.71 (1.17)	17.32 (0.74)
	B	BioQuick	21.50 (0.78)	23.29 (0.80)	25.03 (0.83)	26.91 (0.82)	19.75 (0.47)
	C	In-Ovation C	16.36 (0.28)	17.41 (0.41)	18.87 (0.33)	20.46 (0.51)	14.46 (0.31)
Significant group differences[c]			A: B: C	B: AC	B: AC	B: AC	
0.019″ × 0.025″ ss	A	Mini Sprint	14.12 (0.37)	15.43 (0.32)	16.71 (0.32)	18.02 (0.36)	12.85 (0.25)
	B	BioQuick	18.69 (0.49)	20.23 (0.52)	21.67 (0.50)	23.21 (0.51)	17.27 (0.42)
	C	In-Ovation C	13.03 (0.88)	14.35 (0.86)	15.61 (0.81)	16.87 (0.81)	11.66 (0.52)
Significant group differences[c]			A: B: C	B: AC	B: AC	B: AC	

[a] Comparison between conventional twin bracket (Mini Sprint, Forestadent, Pforzheim, Germany) passive (BioQuick, Forestadent, Pforzheim, Germany) and active SL bracket (In-Ovation C, DENTSPLY Int., York, Pa). Play of the slot in the individual bracket and archwire combinations.

[b] SD indicates standard deviation.

[c] Comparative statistics: The row "significant group differences" shows the ranking of the brackets. Brackets with insignificant differences were grouped and separated from significantly different groups by ":".

Table 2. Mean Torque Angle Required and Standard Deviation to Achieve Moments of 5 Nmm, 10 Nmm, and 15 Nmm in the Case of the RED Dynamic-Elastic Bracket With V Wire.

	Angulation in Degrees	
Moment, Nmm	Mean	SD[a]
5	3.32	0.69
10	7.14	0.96
15	11.28	1.12

[a] SD indicates standard deviation.

show whether moments of 10 Nmm or 3 to 6 Nmm are more suitable for the correct axial positioning of the incisors. Furthermore, the elastic slot enables continuous transmission of moment to the tooth. The elastodynamic bracket shown sets a biological limitation to the magnitude of force and moment. As demonstrated, moments above 20 Nmm could not be exerted because the V wire twists out of the bracket owing to the built-in elasticity of the bracket.

The influence of friction on treatment using elastodynamic brackets can vary depending on the surface properties of the NiTi alloy. Polishing procedures or ion implantation can lead to a clear reduction of friction in orthodontic wires.[23] The potentially high amount of static friction between slot and arch material could be eliminated because of the relative deformability of the superelastic slot wings during chewing. Further studies concerning the friction and surface properties in V-wire mechanics are necessary.

CONCLUSION

- Straight-wire brackets and archwires made of stainless steel can display permanent slot deformation on application of torque.
- With rectangular slot geometry, the play in the slot varied between 11.6° and 19.7°, depending on the bracket manufacturer and the wire dimension tested. This variation makes it difficult to apply torque to the tooth predictably.
- The V slot in combination with the V wire showed no play and therefore allowed direct transmission of torque in the bracket.
- The elastodynamic properties of the NiTi bracket promote more continuous transmission of moment and also set an upper limit to the magnitude of moment that can be applied.
- There was no deformation of the slot of elastodynamic brackets on application of torque because of the elasticity of the brackets.
- The elastic bracket and V-wire combination made of NiTi allowed higher clinical tolerance if the angle of activation was not exact. At an angulation of 7° the torque was 10 Nmm.

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DISCLOSURE

Prof Dr Wichelhaus has codeveloped the RED bracket. The RED bracket is manufactured by Redsystem and she is a shareholder of said company.

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